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Two and Three Color Processing of Fort A P Hill Multiband Imagery

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ABSTRACT

Advanced Navy sensors will operate simultaneously in multiple spectral bands to achieve target detection, discrimination, and identification. Color image processing is necessary to guide the development of integrated imaging sensors using multi-spectral focal plane arrays and to demonstrate the capabilities of these emerging sensors. This paper discusses human visualization techniques which best transfer multi-spectral information to the observer for critical search, surveillance, and targeting decisions. Fused two- and three-band color video is presented from data gathered at Fort AP Hill using bore-sighted cameras (LMIRIS uncooled 320*240 long wave infrared, Amber Radiance 256*256 mid-wave infrared, and Fairchild image intensified CCD cameras).

1. Introduction

Color fusion of multiband imagery, for human visualization, is anticipated to provide increased ability to detect, recognize, and identify targets. The fused image is expected to provide as much or more information than any single band image. This field test was performed to study color fusion of uncooled long wave infrared and low light visible imagery. A third midwave camera was added to study 3-color fusion. The field test was conducted at Fort A P Hill in April 1998. The collaboration participants were Lockheed Martin – Orlando, Lockheed Martin – Fairchild, Lockheed Martin Imaging Systems, PVP Advanced EO Systems, the Naval Post Graduate School, and the Naval Research Lab. Recently available cameras and a novel data acquisition system, which recorded real-time digital and analog data, are described. Imagery of a variety of targets and scenes were collected. The focus of the field test did not include studying optimal band combinations or individual scenes during an entire day. Representative

imagery is presented as both 2-color and 3-color fused images, and as both white-hot and black-hot. Fusion as a correction for loss of information due to blooming and fog is addressed. Finally, a way of measuring the improvement of the fused imagery over single-band imagery, ROC-curves, is presented.

2. Data collection

This field test was novel in that data was recorded digitally from three bore-sighted cameras. One-minute sequences of real-time imagery could be recorded. A sub-goal of the field test was to learn how to assemble a digital data collection system using PC's and frame-grabbers. Fort AP Hill provides a variety of scenes and targets.

2.1. Cameras

The cameras used for this field test were a LMIRIS uncooled 320*240 long wave infrared, an Amber Radiance 256*256 mid-wave infrared, and a Fairchild image intensified CCD camera. The cameras were mounted vertically in a rigid structure, as closely as possible, to minimize parallax in the horizontal direction. The cameras were bore-sighted but did not share a common optic. The fields-of-view of the cameras were: long-wave 33.7 by 26.5, mid-wave 22.4 degrees by 22.4 degrees, and visible 40 degrees by 30 degrees. In the final fused imagery, the camera with the smallest field-of-view, the Amber camera, dictates the image size. No common optic was devised because off-line NRL in-house algorithms exist to rubber-sheet the single band images into a common magnification and orientation.

2.2. Data Acquisition

The data acquisition system recorded both analog and digital data. Storing a one-minute sequence of data allows movement to be included in target detection studies and rare events to be captured. Also, storing digital data allows it to be processed computationally. Analog data must be digitized before any computational analysis can be performed with it and is only 8-bit, so any information over 8-bit is lost. Although, storing analog data is easier, more reliable and does not require huge amounts of computer disk space.

To record analog data, RS-170 cables from all three cameras were recorded to Super Hi VHS-8 tapes. To record data digitally, RS-170 data for the LWIR and visible cameras, and RS-422 for the MWIR camera, were digitized by frame-grabbers in PC's and then stored to high-speed hard disks. The frame grabbers were Imaging Technology IC-PCI cards with AM-FA daughter cards to digitize the RS-170 data and IC-PCI mother boards and AM-DIG daughter cards to digitize the RS-422 data. Data acquisition software, EYE Image Calculator, read data from the frame grabbers and stored the data, in one-minute sequences, in real-time via a SCSI controller, to hard drives. Three PC's were used, one for each camera. Each PC ran Eye Image Calculator and was equipped with a frame grabber. These three computers were networked to a fourth computer, a server with 30GB of disk space, to which the data could be transferred. The RS-422 recorded digitally from the Amber Radiance camera was corrupted and unusable. The analog recording for the Amber Radiance was digitized after the field test for all midwave data that was analyzed. Each one-minute sequence, of all three cameras, is about 0.8 GBytes. A total of 19 GB of visible and longwave digital data and 16 hours of VHS tape for all three cameras were stored. A future improvement to the data acquisition system will be to record 12-bit RS-422 data from all cameras.

2.3. Imagery Scenarios

Data was taken in five different scene scenarios: (1) in heavy clutter, woods, (2) in low clutter, an open field, (3) in medium clutter, a compound of buildings, (4) in medium clutter, along a tree-line, (5) in medium clutter, near a set of buildings and trees. The data was collected in the nighttime, during full moon, and at dawn and dusk. Military targets were an M2, an M113 – a large truck, M60A3 - a tank, an M35, and a HMMWV. People and cars were also used for targets. The ranges of the data were 25 meters in woods scenes, and less than 1 km and up to 5 km in the open fields. GPS data was recorded from the vehicles. Meteorology data also recorded during the field test.

3. Phenomenology and image creation

The cameras were chosen to explore 2-color fusion of the uncooled, long-wave infrared and visible bands. The third mid-wave camera was added to study three-color fusion, since human color vision maps more readily to a three-color system.

The two-band data does not readily correspond to three-color human vision. Instead, since human vision employs color opponency, the two bands are displayed as red and cyan, opponent colors (Ref 1-2). To display the images on a RGB 24-bit display, the longer of the two bands is written to the red color display buffer. The shorter of the two bands is written to both the green and blue buffers. Green and blue combine to make cyan. In this system, the pixels have chrominant values that go from red, through gray, to cyan. In the brightness direction, the pixel values vary from black to white. The three-color data is fused as the longest band to the red buffer, the midwave band to green, and the visible band to blue. All shades of red, green, blue and any combination of the three, plus black, all shades of gray, and white are possible final pixel colors in the 3-color display.

An improvement that can be made to this simple color fusion “algorithm” is to find the principle axis of the distribution of pixels which typically lies along the brightness-darkness direction. Then, for 2-color fusion, a line orthogonal to this direction is the color axis. For 3-color fusion, a plane orthogonal to this direction describes the color of the pixel. Rotating into this principle component space allows the pixels to be normalized so as to maximize differences in the bands and to represent those differences as pixel color.

3.1. Two-color versus Three-color Fusion

Imagery was fused using both two- and three-color fusion. The images have been registered, from the raw data in which all three cameras had different fields-of-view, to match the field-of-view of the Amber camera (Ref 1). In the color image in Figure 1, visible and uncooled longwave infrared images are fused. The top image is from the low light camera. Blooming from the Jeep taillights cause the front of the building to be saturated. The lower image was taken with an uncooled long wave camera at the same time. The fused image, on the right, shows that the truck’s lights were on, from the blue tint of the pixels behind the Jeep, but the windows of the building can be seen using the infrared information. Fused imagery allows a way to “look-through” blooming.

From the same sequence, stills from all three cameras are presented in Figure 2. The top left image is the visible image, the top middle is the midwave image, and the top right is the longwave image. The bottom images are 3-color fusion of the top images. The bottom left image fuses the infrared images as black-as-hot and the bottom right image fuses the infrared images as white-as-hot. The mid-wave infrared image contributes building relief to the fused image and the long-wave infrared image contributes the dark color of the vehicles’ windshields. In the black-as-hot fused image, the Jeep’s windshield appears red, as do the

vehicles in the background near the building in the right side of the image. The Jeep, an extended target, has many colors itself, reminding us that when a target with a certain characteristic, such as a paint color, is searched for, many pixels on that target will be made of additional material with completely different emission and absorption characteristics. A thermal scar has been left in the trail of the Jeep.

This scene is also fused as all combinations of 2-color images in Figure 3. The left column is fused longwave infrared and visible images, the middle column is midwave infrared and visible, the right column is longwave infrared and midwave infrared. The longer of the two bands is represented as red, the shorter as cyan. In the top row, the infrared images are black-as-hot, and in the bottom row, they are white-as-hot. Since the infrared bands are highly correlated, the 2-color fused infrared images appear gray. In the visible-infrared images, the treeline and details of branches and lights in the treeline are apparent from the visible data. The thermal scar and difference in temperature of the building and windows are apparent from the infrared imagery.

To quantify the improvement of target detection of two-color versus three-color, ROC-curves, described in Section 4, are calculated.

3.2. White-hot versus Black-hot Fused Imagery

When analyzing the data, the question was pursued, “Is the target easier to detect if white-hot or black-hot imagery is fused with the visible imagery”. The midwave and longwave imagery, especially at nighttime, is almost entirely self-emitted. The two infrared bands are highly correlated and uncorrelated with the visible band. In Figure 4, a scene of a person in woods, the single images and the three-color fused images show the difference between black-as-hot, the top image, and white-as-hot, the bottom image. Since the data was recorded digitally, it is possible to invert the image. The person is standing in front of a tree trunk in the bottom center-right of the image. Even though the person is very detectable in the midwave data, the ground and sky are both medium-gray in the midwave image. The fused images show good color difference between the sky, trees, and ground. These images can be presented in human performance tests (Ref. 3) to determine if viewers prefer, and perform target detection tasks better, if the imagery is shown as white-as-hot or black-as-hot. Figures 2, 3, and 5 also show both images black-as-hot and white-as-hot fusion.

3.3. Fog and Color Fusion

An image sequence of a military convoy was recorded when there was substantial fog on the ground, early in the morning. The fused images show both information from the visible band, that it was foggy, and from the infrared band, that targets are present, Figure 5. The top left picture was taken with the low light visible camera. The middle image is from the midwave infrared camera. The top right image is from the uncooled long wave camera. The bottom left is a 3-color fused image, black-is-hot, and the bottom right is a 3-color fused, white-is-hot, image. Each single band image lacks information that the fused images have. The visible image does not show the targets and the horizon. The midwave and longwave images do not exhibit the fact that it is foggy. The longwave image does not represent a difference between the road and the ground. In addition, the fused image shows you that the shades of color in the sky are different from the shades of color in the ground, which is important if the horizon is lost to buildings or a treeline.

4. ROC curves

Although some aspects of fusion are not easily measured, one quantitative test of improvement of single band imagery over fused imagery that can be made is a ROC, risk-opportunity curve. A ROC curve is a plot of false alarms versus missed detections. ROC-curves are calculated by setting a series of thresholds and determining what fraction of pixels are above and below the thresholds. False alarms are calculated as the number of background pixels with values greater than the threshold, normalized by the total number of background pixels. Missed detections are calculated as the difference of the number of target pixels minus the number of target pixels greater than the threshold, normalized by the total number of target pixels. This test determines the uniqueness of pixel color or intensity, but does not measure target detection due to target shape. Another analysis, matched filtering, uses target shape as a detection variable.

The calculation of ROC-curves representing the pixel differences of one vehicle in an image of a convoy of military vehicles from the background, Figure 6, will be used as an example. The top left image is a 3-color fused image, fused with the simple color algorithm (Ref 2-3), of the longwave, midwave, and visible bands. These 3-color and a 2-color images are prepared to create ROC curves. The images are then transformed into the principle component space. The vehicles that are not chosen as the target are vetoed, shown in black, so that their pixels will not be counted as false alarms. The sky is also vetoed, so that in the principle component space, the chromaticity plane can be filled with the active pixels, allowing maximum separation of the vehicle pixels from the background pixels. The angles of rotation calculated to rotate into the principle component space, without the vetoed pixels, can be used to present the entire image, including the sky and other vehicles.

For the 2-color fused image, the histogram of the background pixels values along the chromaticity line, after a rotation into the principle component space, is shown in the top plot of Figure 7. In the bottom plot, the histogram of pixel values of the target is plotted. Pixels with values near zero have little color. Pixel values to the left are colored cyan and pixel values to the right are colored red. The target, located at about -0.4 and therefore almost fully cyan, is overlapped by background pixels.

The pixel values in the chromaticity plane after a rotation into the principle component space, are shown in Figure 8. The target pixels are shown as red '*' points between the angles 300 and 330 at the edge of the distribution. There are some background pixels with the same radius, or color saturation, but no background pixels have the same angle, or color hue, and saturation. The target pixels are very well separated from the background pixels.

The ROC curves are plotted in Figure 9. In this plot, a line to the left has a better detection performance than a line to the right. The solid lines to the upper right of the image are the single band curves. For the fusion images, ROC curves were calculated considering only saturation and again considering saturation and hue. For the 2-color images, all of the pixels are considered for the saturation curve, but only the pixels below zero are included in the hue and saturation curve.

The midwave camera performs better than the uncooled longwave or low-light visible cameras. The single band imagery was usually at least an order of magnitude worse than the fused imagery. For the 2-color imagery, a target with very bright pixel intensity is easily detected, but hue does not add additional information over saturation, since there are few background pixels with large red (greater than zero) values. For the 3-color fused imagery, hue does aid in separating the target pixels from the background pixels, placing them in a unique position in the chromaticity plane, as seen in the polar plot in Figure 8. The ROC-curves for the 3-color fused imagery shows much improved target detection over single band imagery when considering pixel saturation alone. When hue and saturation are considered, the ROC-

curve shows another order of magnitude improvement over single band and 2-color fused imagery. This fact shows an improvement in detection of 3-color over 2-color fused imagery.

5. Summary

The Fort A P Hill field test provided good imagery to study 2-color fusion of longwave uncooled and visible imagery and 3-color fusion of longwave, midwave, and visible imagery. In this test, real-time one-minute sequences were recorded digitally, which enables the data to be processed as simple color fusion and principle component fusion off-line. The questions of whether white-as-hot and black-as-hot infrared visible imagery and imagery is better for detection can be studied with this data set using human factors testing. Blooming “look-through” was demonstrated. A hard-to-catch scene of a military convoy in heavy morning fog was recorded. ROC curves for the single bands, 2-color fused images, and 3-color fused images were calculated. The single band imagery was usually at least an order of magnitude worse than the fused imagery. For the 2-color imagery, targets with very bright pixel intensity, i.e. large saturation, are easily detected, but hue does not add additional information over saturation. For the 3-color fused imagery, hue does aid in separating the target pixels from the background pixels, placing them in a unique position in the chromaticity plane. The ROC-curves for the 3-color fused imagery shows much improved target detection over single band imagery when pixel saturation only is considered. When hue and saturation are considered, the ROC-curve for the 3-color fused imagery shows another order of magnitude more improvement over the single band imagery and the 2-color fused imagery.

References

1. P. Warren, D. Scribner, J. Schuler, M. Kruer, “Multi-band Color Fusion”, 1998 Meeting of the IRIS Specialty Group on Passive Sensors, Volume I (unclassified), March 1998.
2. D. A. Scribner, J. Schuler, M. P. Satyshur, S. P. Michaels, and M. R. Kruer, “IRFPA Requirements for Dualband Imaging Sensors”, 1996 Meeting of the Iris Specialty Group on Infrared Detectors, July 1996.
3. M. Sinai, J. McCarley, W. Krebs, “Scence Regonition with Infrared, Low-light, and Sensor-Fused Imagery, 1999 IRIS Specialty Group on Passive Sensor, Volume 1, March 1999.



Figure 1. The top image is from a low light camera. Blooming causes the windows in the building to be saturated. The lower image was taken with an uncooled long wave camera at the same time. The fused image, on the right, shows that the truck's lights came on but has not lost information due to blooming. Fused imagery allows a way to “look-through” blooming.

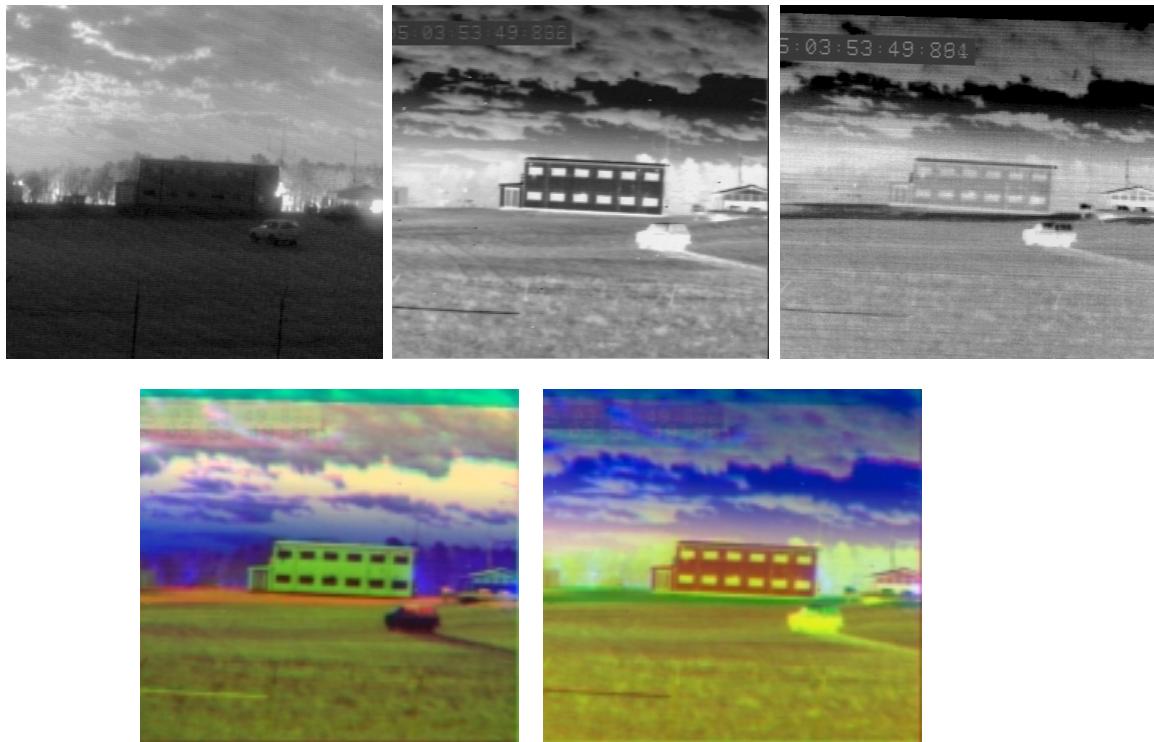


Figure 2. In this scene a Jeep Cherokee is driving through a building compound. The top left image is the visible image, the top middle is the midwave image, and the top right is the longwave image. The bottom images are 3-color fusion of the top images, the left uses the infrared as black-as-hot and the right uses the infrared as white-as-hot. In the fused images, the separation of treeline, clouds and building is more apparent. In the black-as-hot fused image, the vehicles windshield appears red, as do the vehicles in the background near the building in the right side of the image.



Figure 3. All 2-color fusion combinations of the three single bands images in Figure 2 are shown. The fusion algorithm is simple color. The left column shows fusion of the uncooled long wave infrared image with the low light visible image. The middle column fuses midwave infrared with visible and the right column fuses longwave infrared with midwave infrared. In the top row, the images are fused with black-as-hot infrared data. In the bottom row, the images are fused with white-as-hot infrared data. The two infrared bands are highly correlated so that the final images appear gray. The lights in the trees and the tree branches from the visible band and the thermal scar from the infrared bands are apparent in the infrared-visible fused images.

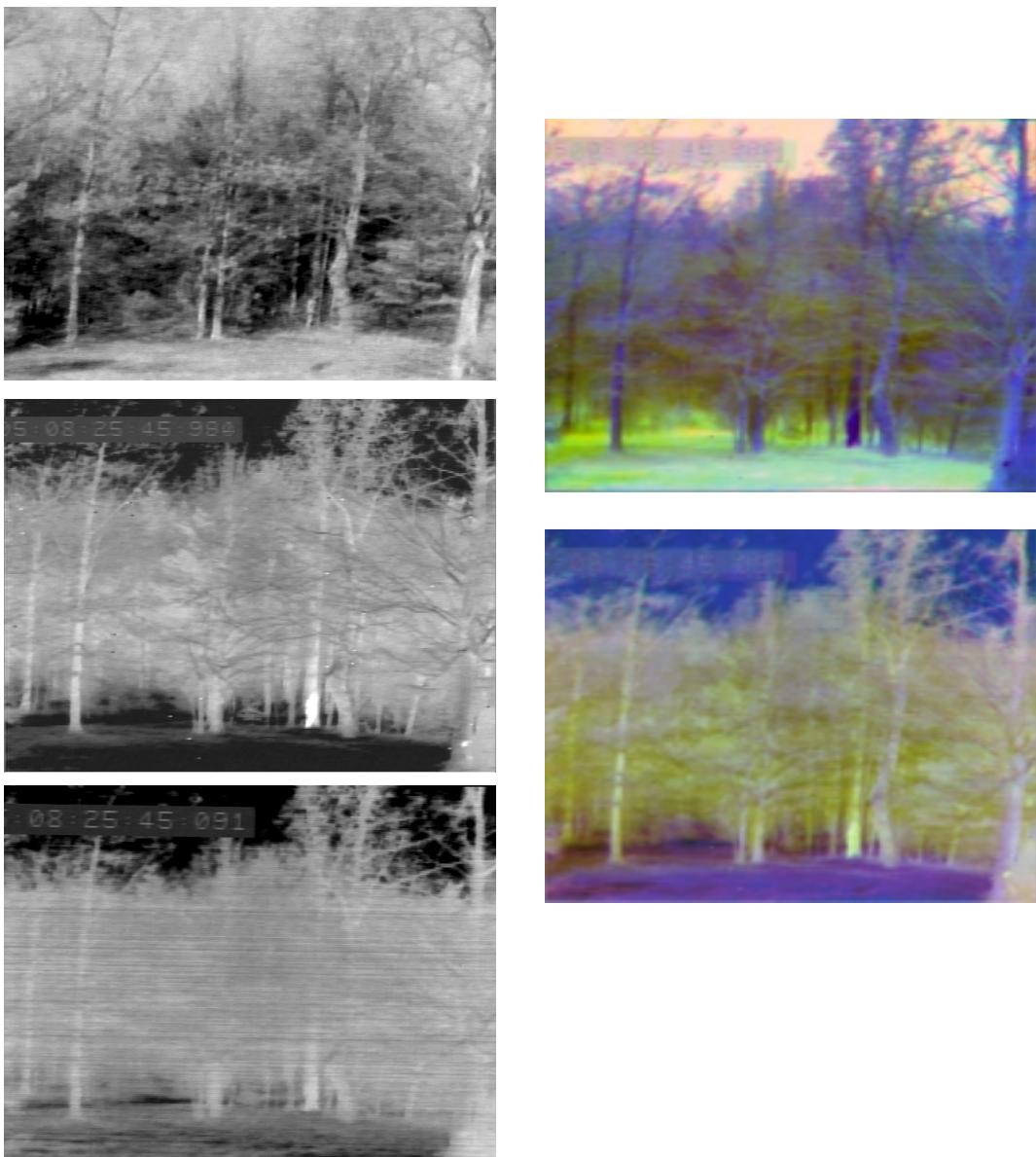


Figure 4. The top image is from a low light camera, the middle from a midwave infrared camera, and the bottom from an uncooled long wave infrared camera. The fused images are black-as-hot and white-as-hot. Notice the sky has a different color from the ground and the trees.

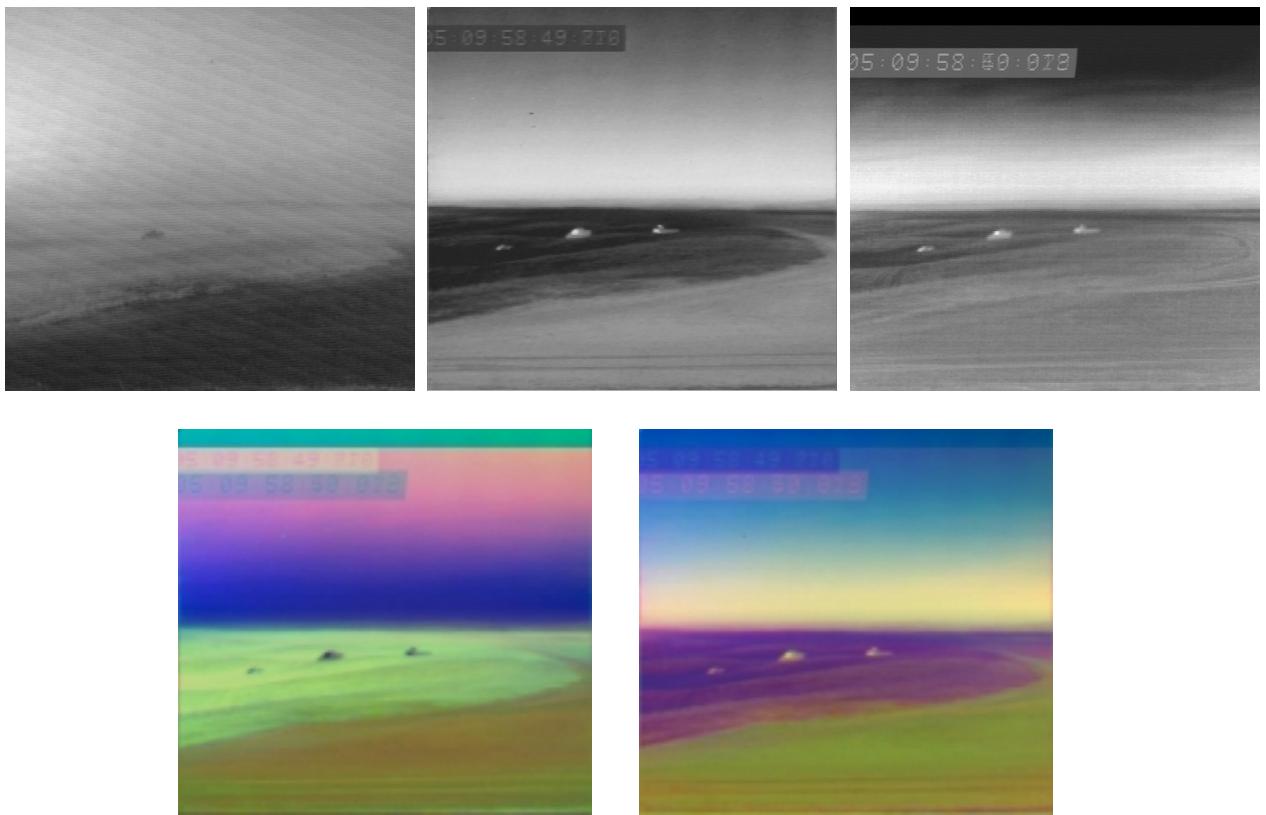


Figure 5. The top left picture was taken with a low light visible camera, during early morning fog. The middle image is from a midwave infrared camera. The top right image is from a uncooled long wave camera. The bottom left is a 3-color fused image, black-is-hot , and the right is a 3-color fused, white-as-hot image. Each single band image lacks information that the fused images have. The visible image lost the targets and the horizon. The midwave and longwave images lost the fact that it is foggy. The longwave image lost the road from the ground. In addition, the fused image shows you that the shades of color in the sky are different from the shades in the ground, which is important if the horizon is lost to buildings or a treeline.

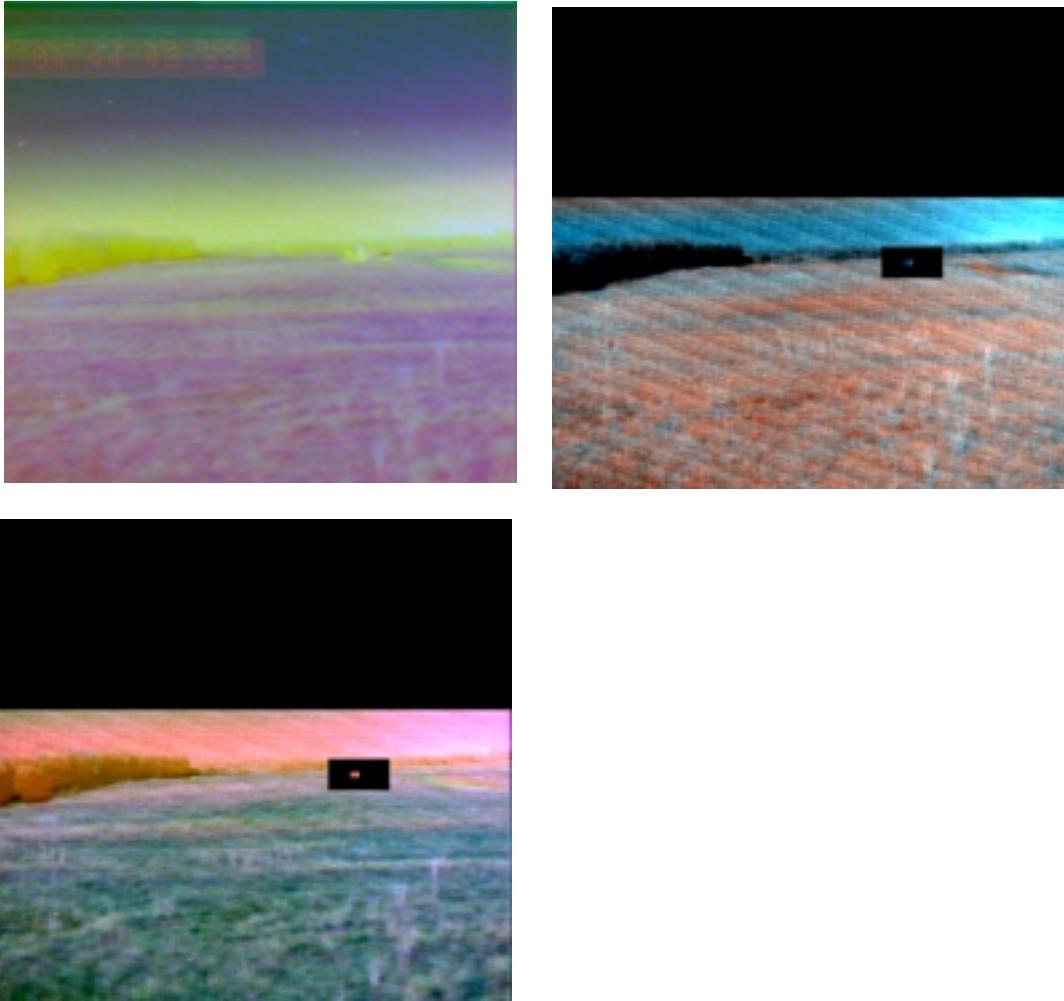


Figure 6. The top left image is a 3-color fused image, fused with the simple color algorithm, of the longwave, midwave, and visible bands. The image shows a convey of military vehicles, located in the right-middle of the image, in front of the tree-line. The image is prepared for processing to calculate a ROC-curve, false alarms versus missed detections, of one of the tanks compared to the background (Figure 8). The prepared 2-color and 3-color, fused with the principle component fusion algorithm, are shown in the top right and bottom left. The vehicles that are not chosen as the target are vetoed, shown as black, so that their pixels will not be counted as false alarms. The sky is also vetoed, so that in the principle component space, the chromaticity plane can be filled with the active pixels, allowing maximum separation of the vehicle pixels from the background pixels. The angles of rotation calculated to rotate into the principle component space, without the vetoed pixels, can be used to present the entire image, including the sky and other vehicles.

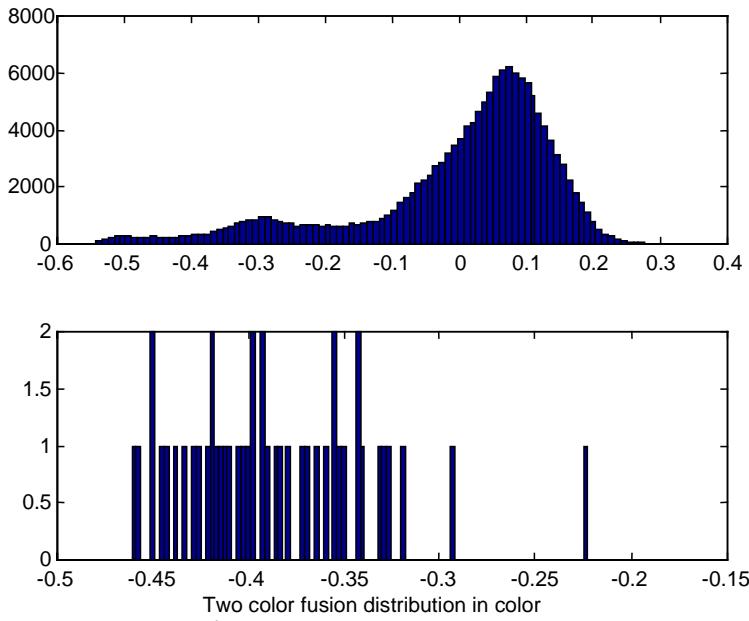


Figure 7. For the 2-color fused image in Figure 5, the histogram of the radius of the background pixels values, along the chromaticity line after a rotation into the principle component space, are plotted in the top image. Pixel values near zero have little color, pixel values to the left are colored purple and pixel values to the right are colored green. In the bottom plot, the pixel values of the target pixels are plotted. The target pixels are overlapped by the background pixels.

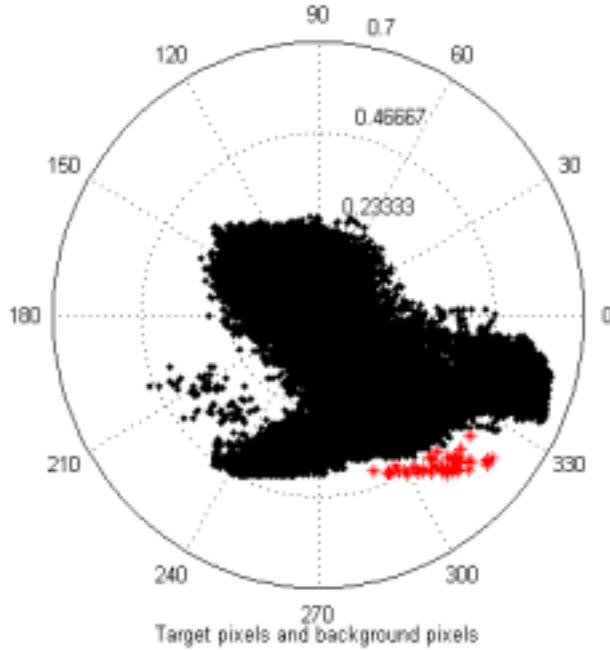


Figure 8. For the 3-color fusion image in Figure 5, the pixel values in the chromaticity plane after a rotation into the principle component space, are shown. The target pixels are shown as "*" points between the angles 300 and 330 at the edge of the distribution. There are some background pixels with the same radius, or color saturation, but no background pixels have the same angle, or color hue, and saturation. The target pixels are very well separated from the background pixels.

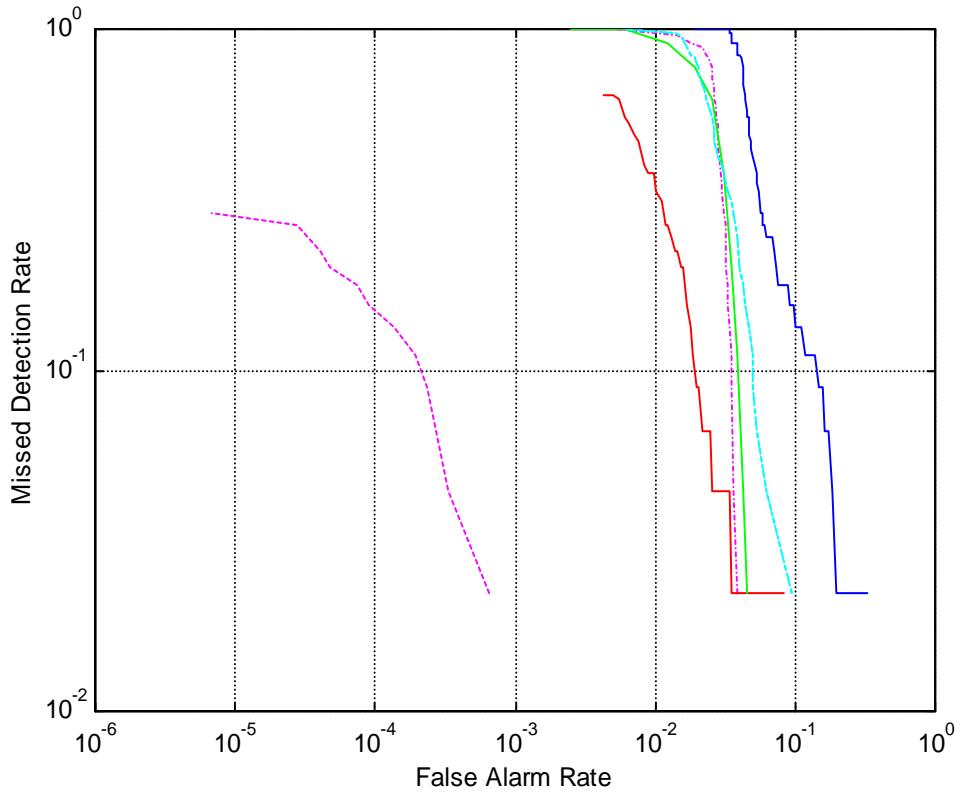


Figure 9. In this Roc curve for Figure 5, a line to the left has a better detection performance than a line to the right. The solid lines to the upper right of the image are the single band curves. The midwave camera performs better than the uncooled longwave or low-light visible cameras. For the fusion images, roc curve were calculated considering only saturation and considering saturation and hue. For the 2c-fusion image, the saturation only and hue and saturation curves are identical. For the 3-color fusion image, making a cut on hue greatly improves detection.